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(54) Variable valve timing operated engine

Brennkraftmaschine mit variabler Hubventilsteuerung

Moteur à commande de calage de soupape variable

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- **PATENT ABSTRACTS OF JAPAN vol. 15, no. 447 (M-1179) 14 November 1991 & JP-A-31 89 336 (MAZDA MOTOR CO) 19 August 1991**

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Description

Field of the Invention

This invention relates in general to an automotive-type engine timing system. More particularly, it relates to one in which the intake and exhaust valves are independently phase shifted to vary the timing to obtain better conditions of operation of the engine.

Background of the Invention

Most commercially available automotive engines use fixed lift, duration and phasing of intake and exhaust valve events. As a result, there is a compromise between the best fuel economy, emission control and engine power conditions.

Potentially better fuel economy, emission control and other engine output benefits can be realised if the timing of these events can be varied depending on the engine operating mode.

This invention is directed to a method of phase shifting both the intake and exhaust camshafts/valves with a unique strategy to achieve the objectives described, and particularly at part load operation.

In general, variable valve timing by means of phase shifting is known in the prior art. For example, U.S. 4,305,352, Oshima et al., describes in Col. 4 and shows diagrammatically in Figures 6 and 7 a variable valve timing system in which late closing of the intake valve is utilised to improve engine efficiency. Oshima et al. calls for a large overlap between the opening of the intake valve and the closing of the exhaust valve for high speed operation, and a smaller overlap for engine idling speed operation.

Oshima et al. for part load operation state that the valve overlap should be increased by about 60° to decrease the amount of NO_x in the exhaust gases. This large overlap is in direct contrast to the strategy proposed by this invention.

SAE Report No. 800794, Tuttle, dated June 1980, describes the advantages of variable valve timing by means of late intake valve closing. However, no specific strategy is provided for operating an engine over the three main operating modes of idle, part load and wide open throttle.

U.S. 4,685,429, Oyaizu, shows a construction for varying the valve timing and is concerned primarily with controlling the valve overlap between intake valve opening and exhaust valve closing. In this case, only the intake valve timing is adjusted. Col. 4 describes and Figure 5 shows the minimum and maximum overlaps, the exhaust valve always opening from bottom dead centre and closing slightly after top dead centre position. No particular strategy is provided for the three primary engine operating modes of idle, part load and wide open throttle. Furthermore, the closing of the exhaust valve only slightly after top dead centre position does not provide the improved engine performance provided by the strategy of this invention to be described.

Object of the invention

The invention, therefore, seeks to provide a method of operating an engine at part load by phase shifting the timing of opening and closing of the intake and exhaust valves to provide controlled internal EGR to control NOx and reduce HC levels, to reduce engine pumping losses, and to improve the expansion ratio.

Summary of the Invention

The present invention, which provides a method of operating an automotive-type internal combustion engine as hereinafter claimed in Claim 1 of the appended claims, is based on varying the valve timing schedules of both the intake and exhaust valves by suitable phase shifting of these events to obtain the most efficient operation during idle speed, part load and wide open throttle operating conditions. At part load, by utilising late closing of the intake valve during the compression stroke and late closing of the exhaust valve during the intake stroke, a variable and delayed valve overlap is provided in accordance with operating conditions between the closing of the exhaust valve and opening of the intake valve to control the exhaust backflow to the cylinder and intake port for internal exhaust gas recirculation (EGR), as well as other benefits.

Brief description of the drawing

The invention will now be described further, by way of example, with reference to the accompanying drawing in which the single figure diagrammatically illustrates the control strategy used by the invention.

Description of the Preferred Embodiment

The figure in general depicts diagrammatically the opening and closing events for both the intake and exhaust valves during the four strokes of the engine so as to better visually understand the strategy or method of the invention.

More specifically, as stated previously, the idea is to phase shift the opening and closing events to obtain better engine combustion, lower emissions and overall better operating efficiency.

- At idle speed operation, it will be seen from the figure that the exhaust valve opens at approximately 66° before bottom dead centre (BDC) position of the piston and closes at approximately 4° after top dead centre (TDC) position in the intake stroke. The intake valve, on the other hand, opens at about 4° before TDC in the exhaust stroke and closes late in the compression stroke about 66° after BDC position. This provides a valve overlap of about 8° essentially symmetrically lo-

cated with respect to TDC position. As a result, the small overlap will optimise combustion stability because the backflow of exhaust gases will minimise the amount of residual gas in the combustion chamber. It also, therefore, permits the engine to idle at a more efficient fuel economy than with a fixed timing schedule. The valve overlap, however, is not completely eliminated because some exhaust gas backflow into the intake port is used to enhance air/fuel mixing to promote combustion efficiency.

For part load operation, both the intake and exhaust events are shifted to the right from the idle speed positions shown to provide a later opening of the exhaust valve and a later closing of the intake valve, with a slightly larger overlap between the two than as before. More specifically, the exhaust valve opens at approximately 26° before BDC and closes approximately 44° after TDC in the intake stroke. The intake valve, on the other hand, now opens in the intake stroke at about 20° crank angle after TDC position and closes late in the compression stroke at about 90° crank angle.

The overlap in this case is increased to approximately 24° allowing the exhaust gas to be mixed with the fresh charge so as to reduce combustion temperatures for controlling the emission of NOx. The delaying of both the exhaust valve closing and the intake valve opening will permit the piston in its early phase of downstroke to draw exhaust gas from the exhaust port into the cylinder. With this strategy, an external EGR system is not required as the delayed overlap between the intake valve opening and the exhaust valve closing provides the amount of backflow and EGR necessary. The exhaust gas backflow into the intake port also promotes air/fuel mixing as pointed out earlier. The exhaust gas expelled last from the cylinder is relatively high in unburned hydrocarbon (HC) concentrations, thus the recirculation of the exhaust gas reduces the HC feed gas level of the engine.

This delayed closing of the intake valve to approximately 90° in the compression stroke, under part load conditions, also results in the backflow of cylinder charge into the intake port in the first part of the compression stroke. This reduces the manifold vacuum and therefore pumping work at a given load, thus increasing fuel efficiency. The delay of the intake event also produces increased swirl that aids in the mixing process, therefore increasing the engine operating efficiency by maintaining adequately high burn rates that are otherwise reduced by the exhaust gas recirculation. The delayed opening of the exhaust valve at low speeds also improves the fuel efficiency due to increased expansion ratio.

The exact shifting of the events will vary as a function of the load. The quantity of air/fuel charge trapped in the cylinder during the compression stroke must be increased when increased torque output is required. This is achieved by closing the intake valve earlier at high loads. This also provides a larger valve overlap for internal EGR control of NOx under high torque operating conditions and under conditions when the manifold vacuum level is low.

Wide open throttle operation is accomplished in this concept by shifting the opening and closing events of the intake and exhaust valves back towards the idle speed positions, as compared to the part load events or positions, but with greater overlap than idle. More specifically, as shown in the figure, at low speed WOT operation, the exhaust valve will open at about 40° before BDC position in the expansion stroke to provide increased expansion work, and close about 30° after TDC position in the intake stroke. The intake valve, on the other hand, will open approximately 24° before TDC position in the exhaust stroke and close early in the compression stroke about 46° after BDC position to provide for trapping a larger volume of cylinder charge.

High speed wide open throttle operation is provided in this case by shifting the exhaust event slightly to the left while moving the intake event slightly to the right, thereby providing earlier exhaust opening and later intake closing, and a smaller valve overlap of about 28°. More specifically, the exhaust valve opens approximately 56° before BDC in the expansion stroke and closes approximately 14° after TDC in the intake stroke while the intake valve opens approximately 14° before TDC position in the exhaust stroke and closes later in the compression stroke approximately 56° after BDC position.

This delayed intake valve closing is desirable to take advantage of the inertia and wave dynamics of the incoming air column in the intake duct. The amount of overlap essentially prevents the exhaust gases from entering the intake port as the exhaust timing is carefully optimised to achieve adequately early blowdown without unduly restricting the final phase of the exhaust process.

From the above, it will be seen that the invention provides a method/strategy of operating an engine by phase shifting the opening and closing timing schedules of the intake and exhaust valves to optimise the operation of the engine for improved idle stability, fuel efficiency and WOT torque/power output. The need for an external EGR system is eliminated by providing a valve overlap with delayed timing in a controlled manner so that EGR is accurately metered under steady state as well as transient conditions.

Claims

1. A method of operating an automotive-type internal combustion engine to control the emission of unburned hydrocarbons and nitrogen oxides while providing efficient engine operation, stable idle, and increased torque and power output, in which method the openings and closings of the engine intake and exhaust valves are varied independently from

fixed valve lift and duration Valve event timing schedules to provide the most efficient speed and torque operation accompanied by optimum fuel economy; and comprising the steps of:

for engine idle speed operation, providing a first small overlap between the opening of the intake valve during the piston exhaust stroke and the closing of the exhaust valve during the piston intake stroke to minimise the amount of residual gas in the engine combustion chamber to increase fuel economy while concurrently providing a minimal backflow of gas into the intake manifold to promote mixing of the air/fuel charge for better combustion stability;
for part load and moderate engine accelerating operating conditions, shifting the intake and exhaust valve timing events by significantly delaying the intake valve opening and the exhaust valve closing from their normal timing schedules and also to provide a greater overlap between the opening of the intake valve and the closing of the exhaust valve than at idle to provide a greater volume of internal exhaust gas recirculation (EGR) into the cylinder and intake port to reduce NOx and HC emissions, the crank angle degree and timing of overlap varying as a function of the load, the gas backflow into the cylinder and the intake port reducing engine pumping losses by reducing the manifold vacuum levels; and characterised by:
for engine wide open throttle (WOT) operating conditions, shifting the valve event timing schedules back towards the idle speed position but with a larger valve overlap than at idle, the overlap decreasing as a function of increasing speed.

2. A method as claimed in Claim 1, wherein the valve overlap at idle is nearly symmetrical with respect to the piston top dead centre position between the piston exhaust and intake strokes.

3. A method as claimed in Claim 1 or 2, wherein during engine idle speed operation, the small overlap advances the opening of the exhaust valve during the expansion stroke away from the piston bottom dead centre position and thereby avoids over expansion.

4. A method as claimed in any one of Claims 1 or 3, wherein during engine part load operation, the intake valve closing is delayed during the compression stroke to provide backflow of cylinder charge into the intake port during the first part of the compression stroke to reduce the manifold vacuum level and pumping losses.

5. A method as claimed in any preceding claim, wherein during engine part load operation, the greater overlap as compared with the overlap during idle and the delayed timing provides for the mixing of exhaust gas with the fresh charge to reduce combustion temperatures and emissions.

6. A method as claimed in any preceding claim, wherein during engine part load operation, the valve overlap with delayed timing provides for the recirculation of exhaust gas that was expelled from the cylinder at the end of the exhaust stroke and is relatively high in unburned hydrocarbon emissions, thereby resulting in reduced overall hydrocarbon emissions.

7. A method as claimed in any preceding claim, wherein during engine part load operation, the exhaust valve opening is delayed during the expansion stroke resulting in increased expansion work and providing greater fuel efficiency.

8. A method as claimed in any preceding claim, wherein during part load operating conditions, the controlling of an overlap duration in the delayed timing position prevents excessive pressure depression as the piston travels in the first half of the intake stroke.

9. A method as in Claim 2 or any claim appended thereto, wherein the valve overlap at idle is in the region of 8° crank angle.

10. A method as claimed in any preceding claim, wherein during high speed wide open throttle operation, the delayed intake valve closing utilises the inertia and wave dynamics of the incoming charge in the intake duct to increase the trapped cylinder charge volume.

11. A method as claimed in any preceding claim, wherein at low engine speed and full torque the intake valve is closed relatively early during the compression stroke to trap a larger volume of charge in the cylinder, and at higher speeds, the intake valve closing is delayed as a function of the increase in speed to trap a maximum amount of charge in the cylinder at all speeds.

Patentansprüche

1. Verfahren zum Betreiben einer Kraftfahrzeug-Brennkraftmaschine zur Regelung der Emissionen an unverbrannten Kohlenwasserstoffen und Stickstoffoxiden bei gleichzeitig effizientem Motorbetrieb, stabilem Leerlauf und erhöhter Drehmoment- und Leistungsabgabe, in welchem Verfahren das Öffnen und Schließen der Motoreinlaß- und -Auslaßventile unabhängig von dem festen Ventilhub und fester Ventilöffnungsdauer verschoben wird, so

daß der bestmögliche Drehzahl- und Drehmomentwirkungsgrad bei gleichzeitig optimaler Kraftstoffersparnis erreicht wird; und welches folgende Schritte enthält:

im Motorleerlaufbetrieb, Herstellen einer ersten kleinen Ventilüberschneidung zwischen dem Öffnen des Einlaßventils während des Auspuffhubes des Kolbens und dem Schließen des Auslaßventils während des Einlaßhubes des Kolbens, so daß der Restgasanteil im Brennraum des Motors auf ein Minimum reduziert und so die Kraftstoffausbeute erhöht wird, während gleichzeitig ein minimaler Rückstrom der Gase in den Ansaugkrümmer gewährleistet wird, um so die Vermischung der Luft/Kraftstoff-Ladung im Hinblick auf eine stabilere Verbrennung zu fördern;
im Teillastbetrieb und bei gemäßigtem Beschleunigen des Motors, Verschieben der Einlaß- und Auslaßventilsteuerzeiten dadurch, daß der Einlaßventil-Öffnungszeitpunkt und der Auslaßventil-Schließzeitpunkt ihrer normalen Einstellung gegenüber deutlich verzögert werden, und daß außerdem eine im Vergleich zum Leerlaufbetrieb größere Ventilüberschneidung zwischen dem Öffnen des Einlaßventils und dem Schließen des Auslaßventils hergestellt wird, so daß ein größeres Volumen an innerer Abgasrückführung (EGR) in den Zylinder und die Einlaßöffnung geschaffen wird, wodurch die NO_X- und HC-Emissionen gesenkt werden, wobei der Kurbelwellendrehwinkel und die Ventilüberschneidung in Abhängigkeit von der Last variieren, wobei der Gasrückstrom in den Zylinder und die Einlaßöffnung die Motorpumpverluste durch Verringerung des Ansaugstutzen-Unterdruckes reduzieren; und

dadurch gekennzeichnet, daß
bei Vollaststellung der Drosselklappe ("weit offener Drosselklappe" - WOT) die Ventilsteuerzeiten zurückgenommen werden in Richtung auf die Leerlaufstellung, jedoch mit einer größeren Ventilüberschneidung als im Leerlauf, wobei die Ventilüberschneidung mit zunehmender Drehzahl abnimmt.

2. Verfahren nach Anspruch 1, worin die Ventilüberschneidung im Leerlauf nahezu symmetrisch in bezug auf die obere Totpunktstellung des Kolbens zwischen dem Auspuffhub und dem Ansaughub des Kolbens ist.

3. Verfahren nach Anspruch 1 oder 2, worin unter Leerlauf-Betriebsbedingungen des Motors die Ventilüberschneidung die geringfügige Öffnung des Auslaßventils während des Expansionshubes von der unteren Totpunktstellung des Kolbens hinweg vorverlegt und damit eine Überexpansion vermeidet.

4. Verfahren nach einem beliebigen der Ansprüche 1 oder 3, worin unter Teillast-Betriebsbedingungen das Schließen des Einlaßventils während des Kompressionshubes verzögert wird, so daß ein Rückstrom der Zylinderladung in die Einlaßöffnung im ersten Teil des Verdichtungshubes entsteht, und daß dieser den Unterdruck im Ansaugstutzen und damit die Pumpverluste reduziert.

5. Verfahren nach einem beliebigen der vorangehenden Ansprüche, worin im Teillastbetrieb des Motors die im Vergleich zur Ventilüberschneidung im Leerlauf größere Ventilüberschneidung sowie die verzögerten Steuerzeiten ein Vermischen der Abgase mit der frischen Ladung bewirken, so daß die Verbrennungstemperatur und damit die Abgasemissionen gesenkt werden.

6. Verfahren nach einem beliebigen der vorangehenden Ansprüche, worin im Teillastbetrieb des Motors die Ventilüberschneidung in Verbindung mit den verzögerten Steuerzeiten die Rückführung derjenigen Abgase bewirken, die gegen Ende des Auspufftaktes aus dem Zylinder ausgestoßen wurden und einen relativ hohen Anteil an unverbrannten Kohlenwasserstoffen aufweisen, wodurch insgesamt niedrigere Kohlenwasserstoff-Emissionswerte erreicht werden.

7. Verfahren nach einem beliebigen der vorangehenden Ansprüche, in welchem im Teillastbetrieb des Motors das Öffnen des Auslaßventils im Verlauf des Expansionshubes verzögert wird, woraus sich eine höhere Expansionsarbeit und bessere Kraftstoffausbeute ergibt.

8. Verfahren nach einem beliebigen der vorangehenden Ansprüche, worin unter Teillast-Betriebsbedingungen des Motors die Steuerung eines Überschneidungszeitraumes in der verspäteten Steuerzeitstellung einen übermäßigen Druckabfall beim Durchlaufen der ersten Hälfte des Ansaughubes durch den Kolben verhindert.

9. Verfahren nach Anspruch 2 oder einem beliebigen der abhängigen Ansprüche, in welchem die Ventilüberschneidung im Leerlauf im Bereich von 8° Kurbelwellenwinkel liegt.

10. Verfahren nach einem beliebigen der vorangehenden Ansprüche, worin beim Vollastbetrieb mit hoher Drehzahl das verzögerte Schließen des Einlaßventils die Trägheit und Wellendynamik der einströmenden Ladung im Ansaugkanal ausnutzt, um so

das Volumen der im Zylinder eingeschlossenen Ladung zu erhöhen.

11. Verfahren nach einem beliebigen der vorangehenden Ansprüche, worin bei niedriger Motordrehzahl und vollem Drehmoment das Einlaßventil relativ früh im Verlauf des Kompressionshubes geschlossen wird, so daß ein größeres Ladevolumen im Zylinder eingeschlossen wird, und bei höherer Drehzahl der Schließzeitpunkt des Einlaßventils in Abhängigkeit von der Drehzahlsteigerung verzögert wird, so daß bei allen Geschwindigkeiten ein maximales Füllvolumen im Zylinder eingeschlossen wird.

Revendications

1. Procédé de commande d'un moteur à combustion interne du type automobile, de manière à limiter l'émission d'hydrocarbures imbrûlés et d'oxydes d'azote tout en procurant un fonctionnement efficace du moteur, un ralenti stable, et une puissance et un couple accrus, procédé dans lequel on fait varier indépendamment l'ouverture et la fermeture des soupapes d'admission et d'échappement du moteur par rapport à des calages fixes de la levée des soupapes et de la durée d'ouverture des soupapes afin de procurer le fonctionnement aux régime et couple les plus efficaces de même qu'une économie optimum du carburant, et comprenant les étapes consistant à :

   pour la marche au ralenti du moteur, prévoir un premier faible croisement entre l'ouverture de la soupape d'admission pendant la course d'échappement du piston et la fermeture de la soupape d'échappement pendant la course d'admission du piston afin de minimiser la quantité de gaz résiduels dans la chambre de combustion du moteur de manière à accroître l'économie de carburant tout en procurant en même temps un retour minimal des gaz dans le collecteur d'admission afin de promouvoir le mélange de la charge air/carburant pour une meilleure stabilité de la combustion,
   pour les conditions de charge partielle et de régime accéléré modéré du moteur, décaler le calage des soupapes d'admission et d'échappement en retardant de façon significative l'ouverture de la soupape d'admission et la fermeture de la soupape d'échappement par rapport à leur calage normal et prévoir également un croisement entre l'ouverture de la soupape d'admission et la fermeture de la soupape d'échappement plus important qu'au ralenti afin de procurer un plus grand volume de recirculation interne des gaz d'échappement dans le cylindre et l'orifice d'admission de manière à réduire les émissions d'oxydes d'azote et d'hydrocarbures, le degré d'angle de vilebrequin et le calage du croisement variant en fonction de la charge, le retour de gaz dans le cylindre et l'orifice d'admission réduisant les pertes par pompage du moteur en réduisant les niveaux de dépression au collecteur, et caractérisé par les étapes consistant à :
   pour la marche gaz ouverts en grand, décaler le calage de la distribution en le ramenant vers la position du ralenti mais avec un croisement des soupapes plus important qu'au ralenti, le croisement décroissant en fonction de la montée en régime.

2. Procédé selon la revendication 1, dans lequel le croisement des soupapes au ralenti est presque symétrique par rapport à la position de point mort haut du piston entre les courses d'échappement et d'admission du piston.

3. Procédé selon la revendication 1 ou 2, dans lequel pendant la marche au ralenti du moteur, le faible croisement avance l'ouverture de la soupape d'échappement pendant la course de détente en l'écartant de la position de point mort bas du piston et évite ainsi une surdétente.

4. Procédé selon l'une quelconque des revendications 1 ou 3, dans lequel pendant la marche du moteur à charge partielle, la fermeture de la soupape d'admission est retardée pendant la course de compression de manière à procurer un retour de charge du cylindre dans l'orifice d'admission pendant la première partie de la course de compression afin de réduire le niveau de dépression au collecteur et les pertes par pompage.

5. Procédé selon l'une quelconque des revendications précédentes, dans lequel pendant la marche du moteur à charge partielle, le croisement plus important par rapport au croisement au ralenti et le calage retardé permettent le mélange de gaz d'échappement avec la nouvelle charge afin de réduire la température de combustion et les émissions nocives.

6. Procédé selon l'une quelconque des revendications précédentes, dans lequel pendant la marche du moteur à charge partielle, le croisement des soupapes à calage retardé permet la recirculation des gaz d'échappement qui ont été chassés du cylindre à la fin de la course d'échappement et présentent une teneur relativement élevée en hydrocarbures imbrûlés, en entraînant ainsi une émission globale d'hydrocarbures réduite.

7. Procédé selon l'une quelconque des revendications

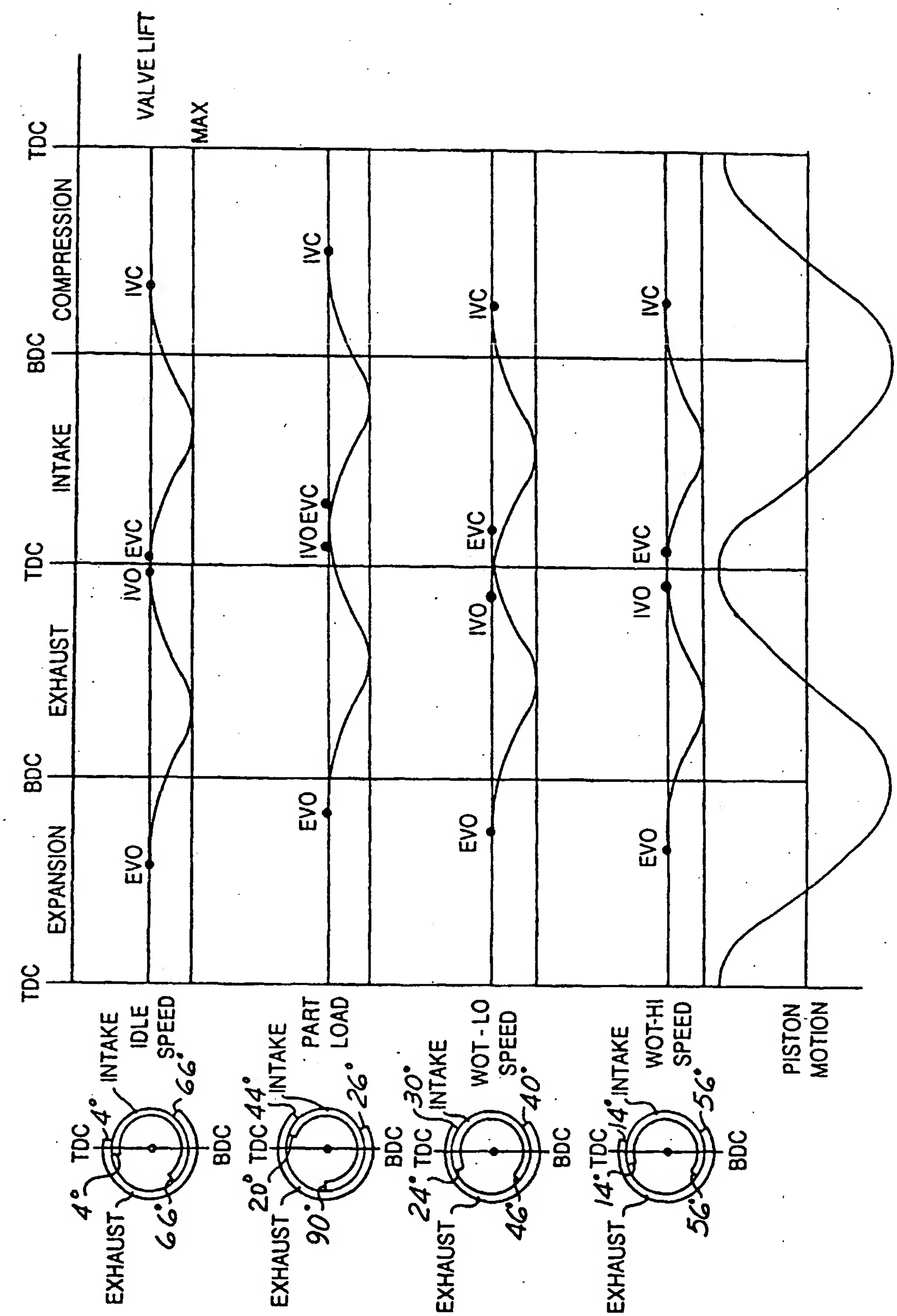
précédentes, dans lequel pendant la marche du moteur à charge partielle, l'ouverture de la soupape d'échappement est retardée pendant la course de détente, en entraînant ainsi un travail de détente accru et procurant une plus grande économie de carburant.

8. Procédé selon l'une quelconque des revendications précédentes, dans lequel pendant la marche à charge partielle, la commande de la durée de croisement en position de calage retardé empêche une dépression excessive lorsque le piston se déplace sur la première moitié de la course d'admission.

9. Procédé selon la revendication 2 ou l'une quelconque des revendications qui en dépendent, dans lequel le croisement des soupapes au ralenti est de l'ordre de 8° d'angle de vilebrequin.

10. Procédé selon l'une quelconque des revendications précédentes, dans lequel pendant la marche à haut régime gaz ouverts en grand, la fermeture retardée de la soupape d'admission utilise l'inertie et la dynamique vibratoire de la charge entrant dans le conduit d'admission pour accroître le volume emprisonné de charge du cylindre.

11. Procédé selon l'une quelconque des revendications précédentes, dans lequel à bas régime et couple maximum, la soupape d'admission est fermée de façon relativement précoce pendant la course de compression afin d'emprisonner un plus fort volume de charge dans le cylindre, et aux régimes plus élevés, la fermeture de la soupape d'admission est retardée en fonction de la montée en régime afin d'emprisonner une quantité maximum de charge dans le cylindre à tous les régimes.


VALVE LIFT
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